Journal of Multidisciplinary Engineering Science and Technology (JMEST)
ISSN: 3159-0040
Vol. 2 Issue 6, June - 2015

Gis-Based Source Water Vulnerability Assessment Of Otamiri River, Owerri S.E Nigeria

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***Abstract*—Otamiri watershed is surface source water in an urban watershed. Siltation, sedimentation and devastating stream back erosion of the river are observed to be consequences of intense human activities within the immediate watershed. The paper utilized the Geographic Information System tool to assess source water vulnerability based on the nature of activities occurring in the watershed. The research method included watershed survey, land use classification and spatial analysis techniques. The spatial analyst tool in ArcGIS 9.3 was used to delineate the contributing watershed, classify the level of imperviousness using ISAT extension, generate slope characteristics and cost distance of the area. These different spatial layers were integrated and their percentage influence altered to bring about different scenarios to estimate the potential source water vulnerability level. From the vulnerability assessment it was also observed that the study area had a composite vulnerability classes that target mainly medium and low vulnerability zones in the watershed. This can be said to be as a result of the relatively flat slope of the area which has the tendency to increase the rate of infiltration rather than runoff rate thereby posing a threat to ground water other than surface water.**

Keywords—Source Water; GIS; Vulnerability; Source Water Assessment; Watershed

1 INTRODUCTION

Clean and safe drinking water is fundamental to the viability (health, development and environmental stability) of any community. Source water in particular is essential because it is water (groundwater or surface water) in its natural state, prior to any treatment for domestic or industrial purposes The protection of the water sources can be said to be a wise and relatively an inexpensive investment in a community's future (Bice *et al.,* 2000). From the historical perspective one can say that drinking water source has played a key role in the location and development of communities (EPA, 1997). The development of a community which in the modern context cannot be said to be a function of public drinking water system or supply, but may be dependent on other factors such as industrialisation, tourism, commercialisation, agricultural dependency factors such as soil fertility and so on. All the above mentioned agents of development will relate in one way or the other to the way a land can be put into use. Land is one of the most important factors that can affect the quality of surface water in a watershed (Eckharodt and Stackellberg, 1995); since land use can be said to house the two major forms of pollution i.e. Nonpoint source pollution and Point source pollution. Source water potential vulnerability assessment provides a method to identify and prioritize potential risks to human health and the environment by identifying areas or surfaces in the watershed that are likely to impact on the source water. Source water vulnerability assessment is based on the manipulation of some terrain/ environmental characteristics of the watershed such as river proximity to land uses on the watershed, slope, impervious surfaces and land use activities. In a bid to spatially arrange and integrate the environmental factors such as land use, slope, impervious surfaces and land use distance from the river to aid the understanding of the level of the watershed vulnerability to source water contamination; the Geographic Information Systems is thus a justifiable tool for this analysis. Since the Geographic Information Systems can organize, analyze, and manipulate available geographic data, generate new data and it provides the capability for presenting (Visualisation capability) the data to the public in various forms, including maps and tables (Bice *et al.,* 2000). Therefore GIS technology can be applied virtually in every stage of the assessment which are watershed delineation, land use land cover classification, generation of working maps for field verification, also visual and spatial analysis, by utilizing the full advantage of its data integration, analysis and visualization capabilities.

11 Study Area

The study area is Otamiri River watershed with its tributary- Nworie River and the immediate environment. Otamiri river watershed is a micro-watershed of the greater Imo river basin. The river with the length of 105 kilometers is the principal tributary of Imo River-a major river that washes through the landscape of Imo state (Imo State Govt. Ministry of Works & transport, 1984). Imo state has a high population density; available statistics show that the study area has a population density of 813.54 persons per square kilometre (Federal Republic of Nigeria, 2009). The study area covers upper sections (longitude 70 0’ 12” E and 70 5’ 18” E and latitude 50 26’ 06”N and 50 39’ 48”N) of the watershed in Owerri Capital Territory facing threat from urbanization. The communities are Egbu, Owerri and Nekede settlement. See figure 1.0. .,

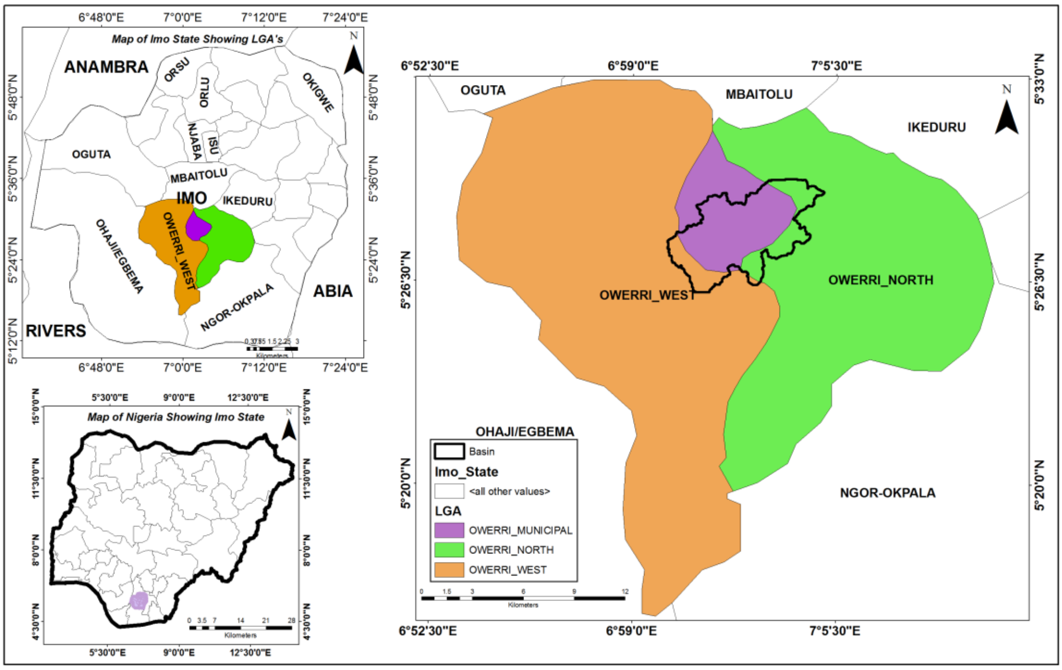

Figure 1: Map of Nigeria Showing Imo State and Study Area.

Owerri capital territory is located between latitudes $05^0 25^1$ and $05^0 32^1$ North and longitudes 06^0 57^1 and 07^0 07^1 East. Rainfall is the greatest climatic variable with annual total mean of 2190mm (Imo State Govt. Ministry of Works & Transport, 1984). The mean monthly temperature for dry season is 34^oC and 30^oC for rainy season. The river has average flow of $10.7m^3/s$ in the rainy season (September – October) and a minimum average flow of about $3.4m^3/s$ in the dry season (November to February).The total annual discharge of the Otamiri is about $1.7{\times}10^8 m^3$, and 22percent of this ($3.4 \times 10^7 m^3$) comes from direct runoff from rainwater and constitutes the safe yield of the river (Egboka and Uma, 1985).

Literature Review

Source water refers to all natural water sources that are used as input for public/private water supply systems. Source water assessment is a critical element of source water protection program, if public health is to be sustained (AC-Chukwuocha, *et al.,* 2009). It is a mandatory program for the public water supply agencies who are concerned with health and water delivery to the public (Bice *et al*. 2000; USEPA, 2000). Program Report of New Mexico Water Utility, 2004 outlined the following benefits as associated with source water assessment:

- Prevent adverse effect upon human health and the environment.
- Protect the environmental integrity of the state water resources
- Serve as an information gathering tool to identify, evaluate and prevent contaminants from polluting public drinking water systems

If the source of water is not duly protected the resultant effect could be water pollution which will alter the physical, chemical and biological process of the aquatic environment thereby making it inhabitable for the aquatic creatures. This alteration might occur in form of decrease in the oxygen, eutrophication, acidification, temperature change, increased microbial loads, introductions of hydrocarbon and heavy metals. (Peavy *et al.,* 1985; Kiely, 1998;Weiner and Mathews, 2003). Human health effect associated with water pollution will occur as a result of direct (e.g. drinking contaminated water) or indirect (food chain poisoning i.e. bioaccumulation and biomagnifications) interaction with the water source, similarly the chemistry of drinking water commonly has been cited as an important factor in many diseases (Salem *et al.,* 2000). The increasing growth in urban development in our cities has begun to put under serious threats, the treasured physicochemical and biological qualities of the surface and ground water resources (Umunnakwe and Nnaji, 2011). This is as a result of land use can change from one land use to another upon natural and human interference. The resultant change will give rise to great increase in the human population and density, productivity, incomes, consumption patterns, technological, political, climate change and also unsustainable land use as the driving forces of land use change (Dent *et al.,* 2009). Saleska, (2010) considers land use change as a major climate change driver in his work "GLOBAL CHANGE DRIVERS".

Geographic Information Systems techniques could be applied in almost every stage of the project, including watershed delineation, mapping of potential pollutant sources or land use classifications, generation of working maps for field verification, and visual and spatial analysis (DiGirolamo, 2001). Barry *et al*., (2003) applied geographic information system to conduct source water assessments for small community water systems in Pennsylvania.

111 MATERIALS AND METHOD

The table 1 below, is a table containing the materials used in the assessment of source water potential vulnerability of Otamiri River.

Table 1: Data Description

MATERIALS	DATA REQUIRED	PURPOSE
GPS Garmin ETREX Vista	**Co-ordinate values**	**Watershed survey and Ground truthing for accuracy assessment.**
GEOGRAPHIC INFORMATION SYSTEM Software (ESRI Arc Info 9.3)	**Database design, creation, integration of data, processing and spatial analysis, map representation**	**Watershed characterisation, reclassification mapping,**
INTERVIEW	**History of the study area, definition of magnitude of potential release.**	**Background and Visual Survey**
SRTM satellite imagery (Digital Elevation Model)	**Watershed delineation, drainage network and slope.**	**Watershed Mapping**
Administrative Map of Imo State	**Digital map of study area**	**Mapping**
2012 Google Earth Extraction Satellite imagery	**Land use/land cover distribution/pattern**	**Land use and land cover classification.**
Field log book	**Characteristics of the watershed**	**Field survey**

IV METHODS

The method applied in the study followed the United State Environment Protection Agency (USEPA, 2000), standard approach to source water assessment. The approach includes the four (4) basic elements below:

- Delineating (or mapping) the watershed
- Conducting an inventory of potential sources of contamination in the study area
- Determining the susceptibility/ vulnerability of the source water to contamination sources
- Releasing the results.

The USEPA (2000) source water assessment procedure was modified in the study. Prior to GIS analysis in the study, a Personal Geo-Database was created in the ArcCatalog. The geo-database was designed to house the two geographic data models (vector and raster models) that were applied in the project. The rectified 2012 Goggle Earth image extraction was acquired from the Center for Remote

Sensing in Jos, Nigeria. The image is built in a projected coordinate system-World Geodetic System (WGS), Universal Transverse Mercator (UTM) zone 32N.

A Watershed Survey

Watershed survey which involved background investigation and visual assessment of the study area was carried. The background investigation provided information on the history of the river and its watershed resources. While visual assessment served as the ground-truthing or verification process for the acquired land use data. The information acquired from the physical observation of the area served as a platform for the reclassification of the land use by attributing threat values to the various land use.

BWatershed Delineation

HEC-GeoHMS extension in the ArcMap (Arc Info 9.3) platform was utilized in this process., Its terrain pre-processing function with the terrain model input i.e. the Digital Elevation Model (DEM) of the study area and an already existing stream feature were used to derive eight (8) additional datasets (flow direction, flow accumulation, stream definition, stream segmentation, Catchment Grid Delineation, Catchment Polygon Processing, Drainage Line Processing, and Adjoint Catchment Processing). These collectively describe the drainage pattern of the watershed and also aided in the delineation of stream and sub basin. In the terrain pre-processing the Raw DEM was reconditioned to lower the grid cell along line feature (already existing stream feature), after this process the output DEM (Agreed DEM) was filled to remove depressions or sinks in the existing model by increasing the elevation of the depressed cells to the level of the surrounding terrain. This hydrologically corrected DEM was used as the starting point for delineating sub basins and river reaches.

CLand Use Classification

Modified version of Anderson (1976) level IV land use classification scheme was employed. Basic on researcher's prior knowledge of the study area, nine classes were created. They are light vegetation/ farmland, thick vegetation, bare surfaces, built up area, excavation sites, waste dumpsites, roads, riparian vegetation and water body. The classes where obtained by polygonization of the satellite image into the various themes. An accuracy assessment was carried out by the use of error matrix. Ground-truthing excise and accuracy assessment were carried out before the data application in the analysis. Ground-truthing was carried out with the use of GPS (Global Positioning System) to collect the co-ordinates of the randomly selected land uses, these were used in the verification process during editing of the classified maps.

The resultant land use data were reclassified to obtain a potential land use impact to surface water map. The reclassification was categorized into five classes- Very High (5), High (4), Medium (3), Low (2), and Very Low (1). The highest rank was given to the land use classes with the highest negative impact. The criteria adopted for land use reclassification was based on the land use impact potential and its presumed magnitude of contaminant release. During the reclassification water bodies and riparian vegetation had "No Data" as they were assumed to have no negative impact since the water bodies were under the protection by the riparian vegetation. The table 2 below shows the impact category allocated to the different land use classes. The reclassification was carried out with the reclassify function in the spatial analyst tool of ArcGIS 9.3. Prior to the reclassification the land use data were merged and converted to raster data format, the entire processes involved in the reclassification is shown in Figure 2.

Table 2: Ranking of Land use Impact Potential

LAND USE	Ranks
Light Vegetation/ Farmland	2
Thick Vegetation	1
Bare Surface	3
Built up Area	5
Excavation Site	4
Waste Dumpsite	5
Roads	5
Riparian Vegetation/ Water body	No Data

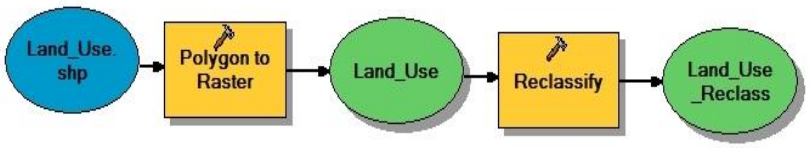

Figure 2: Land Use Reclassification process model

D Generating Slope

Percentage slope was generated from the Digital Elevation Model . The watershed shapefile was used to clip out the study area and then generate the slope of the study area using the model builder and spatial analyst tool as shown in Figure 3 below.

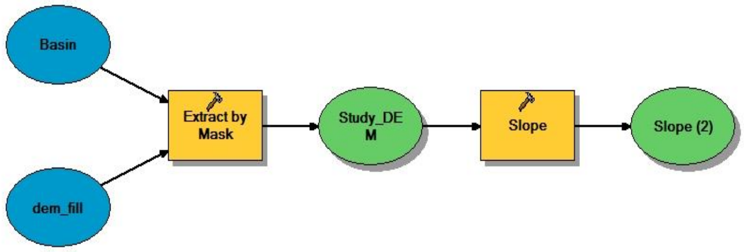

Figure 3: Slope Generation Process Model

D. I Reclassifying Slope

The derived slope values were classified into five equal parts and ranked based on the already developed ranking category- Very High (5), High (4), Medium (3), Low (2), and Very Low (1). The steepest had the highest rank of 5 (Very High) since runoffs will migrate faster through a steeper slope to surface which might in turn alter the water quality. Figure 4 below describes the process involved in reclassifying slope.

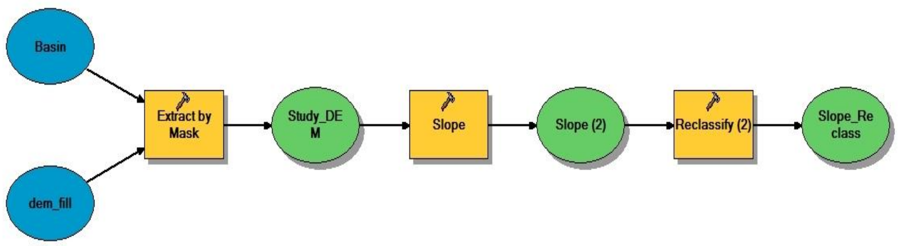

Figure 4: Slope reclassification Process Model

E. Impervious Surface Analysis

The Impervious Surface Analysis Tool (ISAT) was integrated into the GIS platform, to analyse the level of imperviousness of the study area. This was carried out by inputting the land use grid and the sub basin layer as the required land cover and analysis layer into the ISAT environment. Also a coefficient was set based on the land uses to establish population density for sub basins in the study area.

F. Creating Cost Distance Layer

The cost of contaminants migrating through the various land uses was identified. The cost was then transformed into a thematic layer. The Cost distance function is supported in the Arc Info 9.3. It is an appropriate tool for modelling migration through an impedance field (Jeffery and Onwuteaka, 2001). The models treated vulnerability as a translation of cost i.e. the lower the cost of migration of contamination through the landscape, the greater the risk of hazard. Below is figure 5 showing the process in creating as well as reclassifying the cost distance layer in the study.

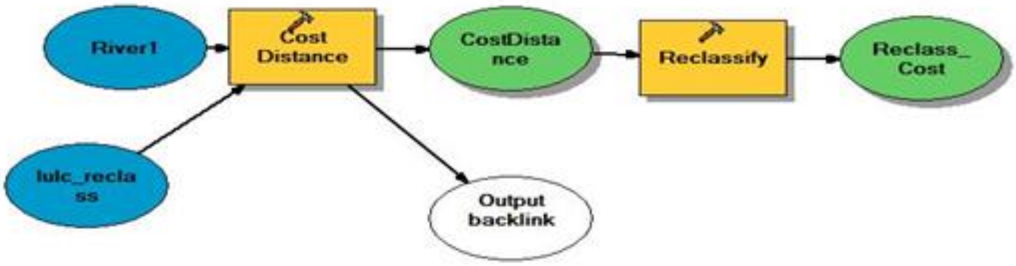

Figure 5: Process model of creating and reclassifying the cost distance layer.

F. Integration of the Thematic Layers with GIS

The different thematic layers obtained where integrated in the GIS with the aid of the spatial analysis function. In order to develop different scenarios individual weights were altered based on the assumptions of the relative importance of the different thematic layers in determining the source water vulnerability. Five (5) scenarios or strategies were employed. In the first strategy the overall weight of the layers were equal, in the second scenario land use assumed a higher influence with 40% of the overall weights. the strategy alternates for all the five (5) scenarios as seen in the table 3 below which describes the ranks and weighting for various parameters for the Source Water vulnerability. This process was carried out using the model builder and weighted overlay tool in the spatial analysis function.

Table 3: Ranks and Scenario weighting for the different Thematic Layers for the Vulnerability Analysis

Thematic Layers	Scenario Weights					Individual Features	Ranks
	1	2	3	4	5		
Land use	25	40	20	20	20	Light Vegetation/ Farmland	2
						Thick Vegetation	1
						Riparian Vegetation	NoData
						Bare Surface	3
						Built-Up	5
						Excavation Site	4
						Water Body	NoData
						Road	5
						Waste Dump	5
Slope	25	20	40	20	20	1	1
						2	2
						3	3
						4	4
						5	5
Imperviousness	25	20	20	40	20	1	1
						2	2
						3	3
						4	4
						5	5
Cost Distance	25	20	20	20	40	1	1
						2	2
						3	3
						4	4
						5	5

G. RESULTS AND DISCUSSION

G. 1. Watershed Land Use Distribution

The figure 6 below illustrates the land use activities and its distribution on the watershed understudy, while table 4 shows the percentage coverage of the various classes of land use and land cover. Built up area is the predominant land use in terms of areal extent on the watershed and composes of 45.5% of the entire watershed while waste dump site was the land use with the least areal extent occurring on the watershed which occupied approximately 0.01% of the entire study area. The large extent of the built up areas can be said to be the evidence of urbanisation trend in Owerri municipal and its environs. From the visual assessment the built areas were mainly a function of residential buildings, road networks, commercial and industrial centers such as block industries, auto salvage works, transport terminals and significant impact of sand mining activities.

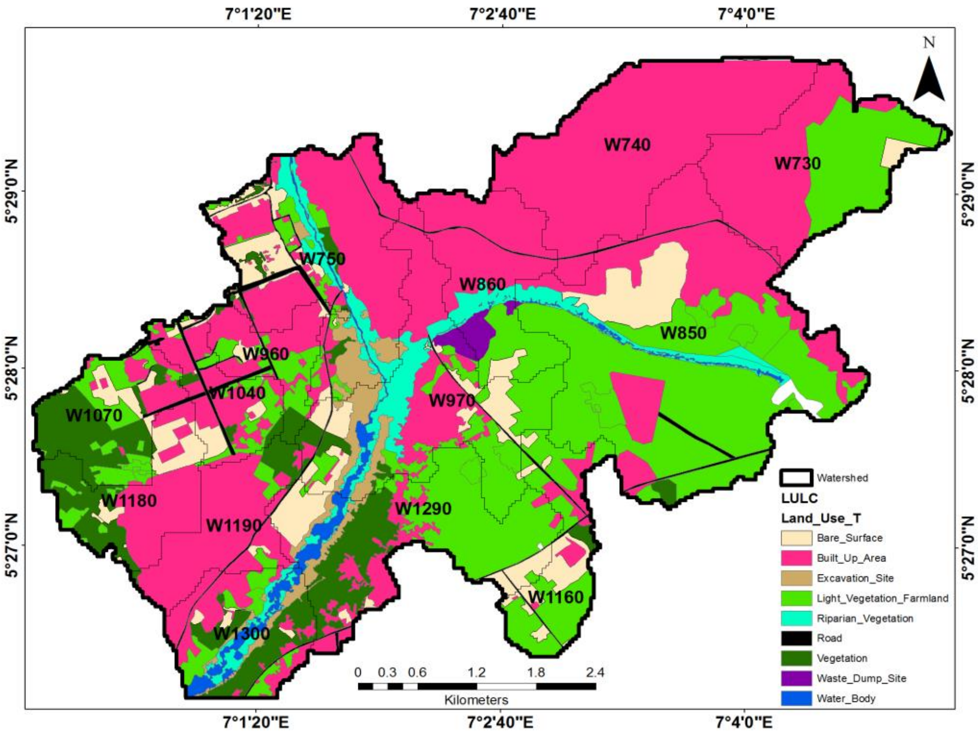

Figure 6: Map of study area sub watershed showing Land Use Distribution

Table 4: Land Use Percentage Distribution

LAND USE TYPES	PERCENTAGE DISTRIBUTION (%)
Light Vegetation Farmland	28.39615893
Thick Vegetation	8.026792101
Riparian Vegetation	4.031821039
Bare Surface	8.122168513
Built Up Area	45.50972189
Excavation Site	2.393080875
Water Body	1.294084495
Road	1.669087204
Waste Dump Site	0.55708495

G. 2 Level of Imperviousness

The result of the impervious surface analysis as shown in figure 7 shows that about seventy-one (71.4%) percent of the sub watersheds were between 10% to 25% imperviousness while two (2) out of the remaining four (4) were above 25% imperviousness while the remaining two (2) were below 10% imperviousness. the dominance of the 10% to 25% imperviousness explains the reason for the water quality discussed later according to Schueler, (2003).

A breakdown of the percentage impervious surface can be seen in table 5 below.

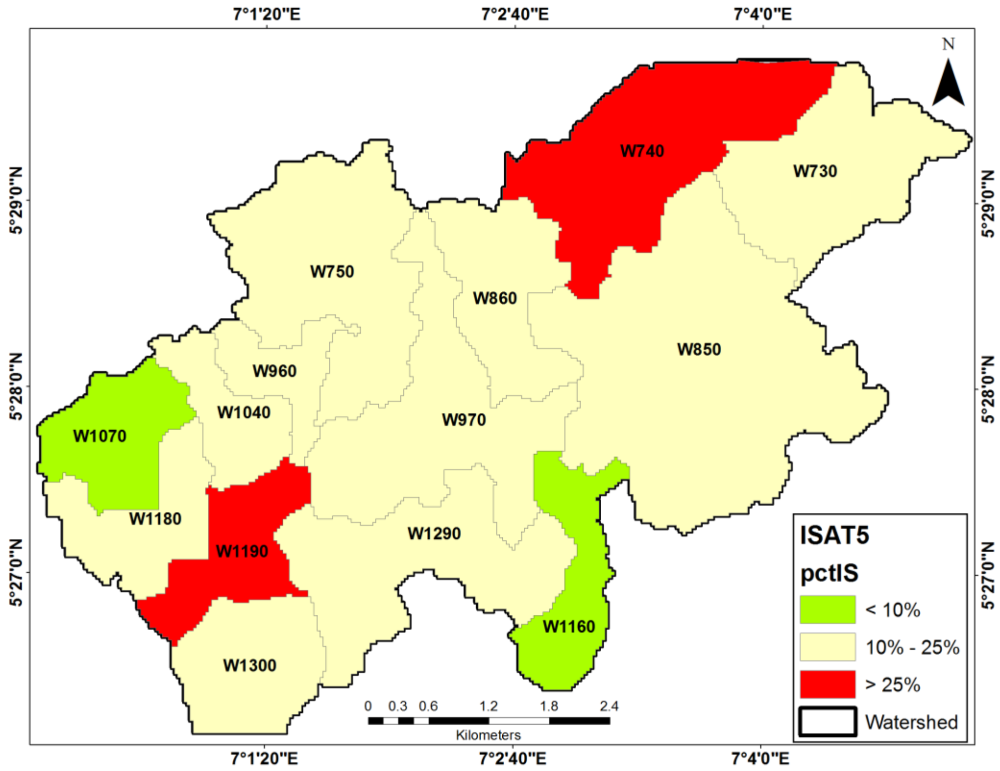

Figure 7: Map of Showing Study Area Imperviousness.

Table 5: Area and Percentage Impervious Surface

Sub Watershed Codes	Total Area of Sub Watershed (Sq. M)	Total Area of Impervious Surface (sq. M)	Percentage Impervious Surface
W1040	1,050,489	2,026.62	19.29
W1070	1,456,542	1,178.28	8.09
W1160	1,340,631	1,286.54	9.60
W1180	1,454,355	2,473.64	17.01
W1190	1,397,493	3,570.71	25.55
W1290	2,972,862	3,051.01	10.26
W1300	1,669,410	2,246.85	13.46
W730	2,633,877	5,061.81	19.22
W740	3,471,498	10,401.37	29.96
W750	3,483,891	7,399.64	21.24
W850	6,663,789	8,587.55	12.89
W860	1,836,351	3,718.70	20.25
W960	853,659	1,589.58	18.62
W970	3,346,110	4,985.78	14.90

G. 3 Watershed Slope

The percentage slope of the watershed described the relatively flat surface nature of the area as seen in figure 8 below. The average sub watershed slope is 5.99%.

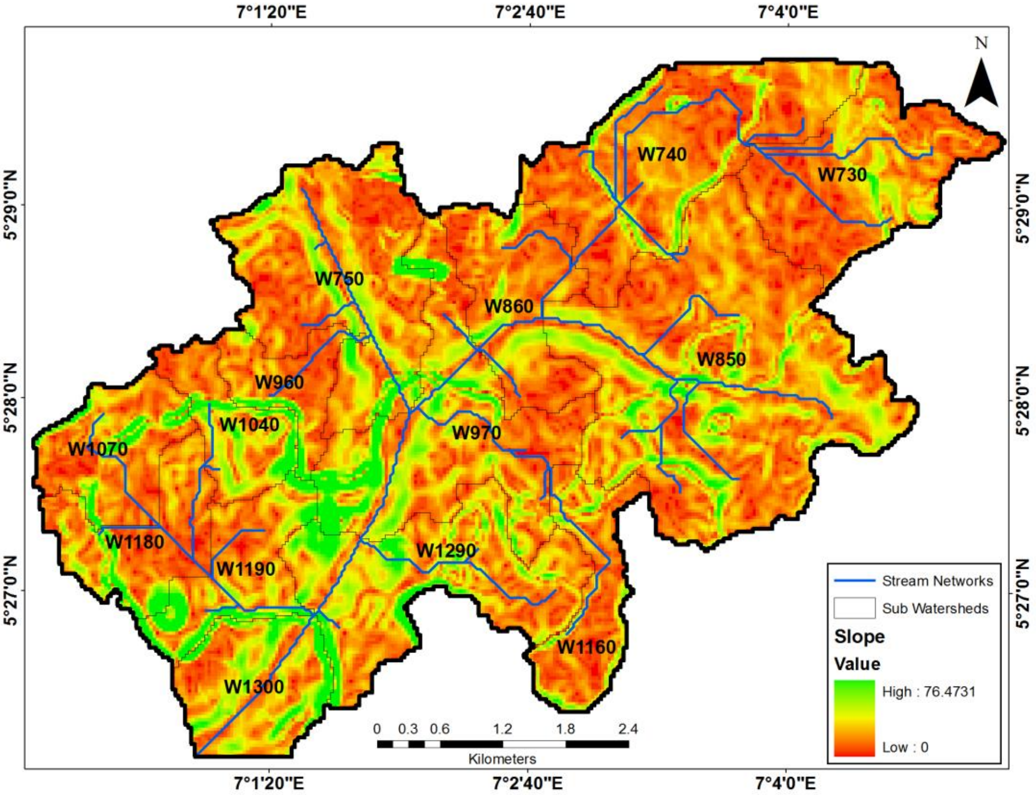

Figure 8: Map showing the Percentage Slope of the Study Area Watershed

G. 4 Cost Distance

This layer measures the cost of contaminant migration from a land use type to surface water The map below in figure 9 is the result from the cost distance analysis with the light orange colours representing areas of low cost i.e. areas with a high possibility of source water contamination while the blue section represents areas of high cost.

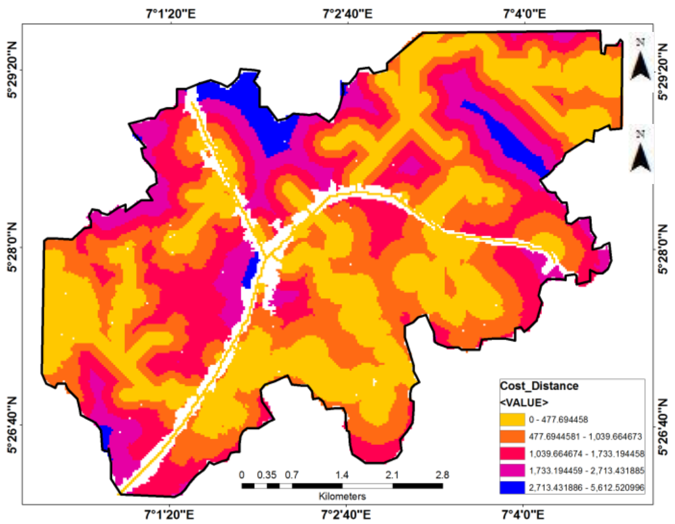

Figure 9: Result of Cost Distance Analysis

G. 5 Accuracy Assessment

The acquired data during the field survey/ visual assessment were used to generate an error matrix, and the percentage of the correctly classified field relating closely to the USGS standardised minimum level of interpretation accuracy of 85% with an accuracy percentage of 82.2%.

G. 6 Vulnerability Classes

The maps presented in figures 10 – 14 show the output from the vulnerability assessment for the five scenarios. These scenarios point out the relative influence of weighting of the different thematic layers.

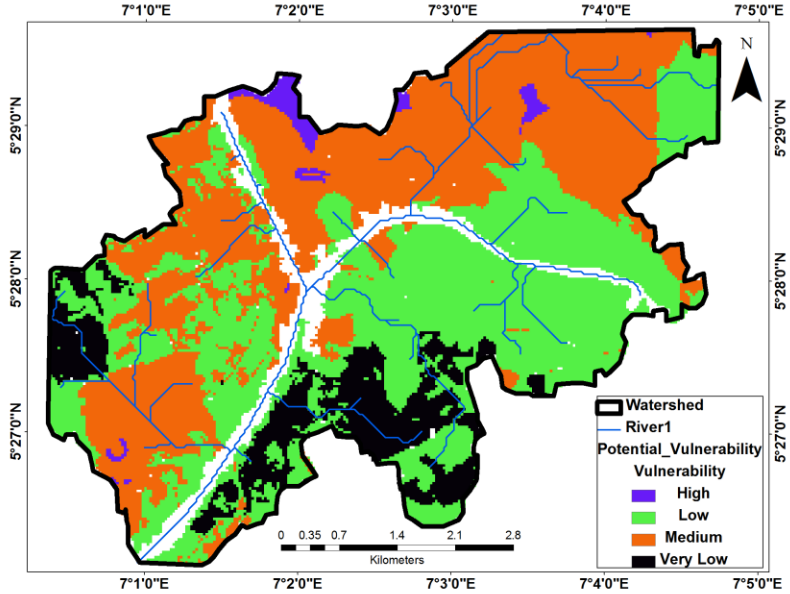

Figure 10: Scenario 1: Map showing Result of Equal Weightings for all Thematic layers

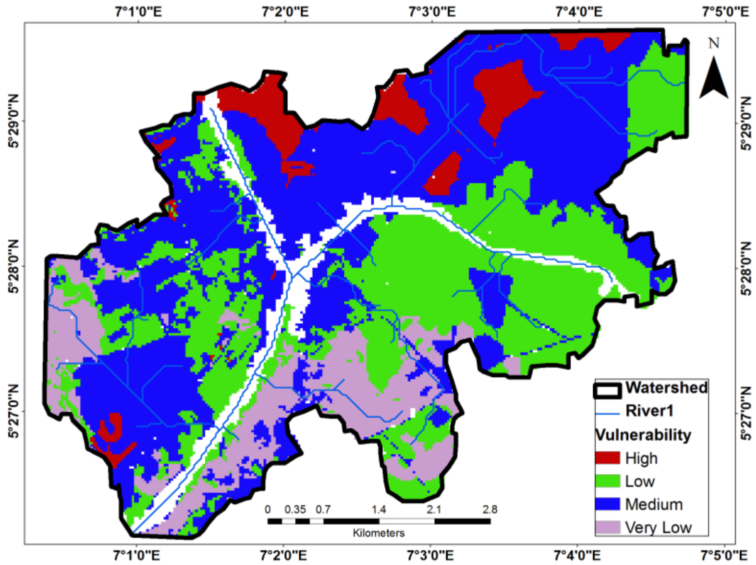

Figure 11: Scenario 2: Map showing Result of greater Weighting for Land Use Layer

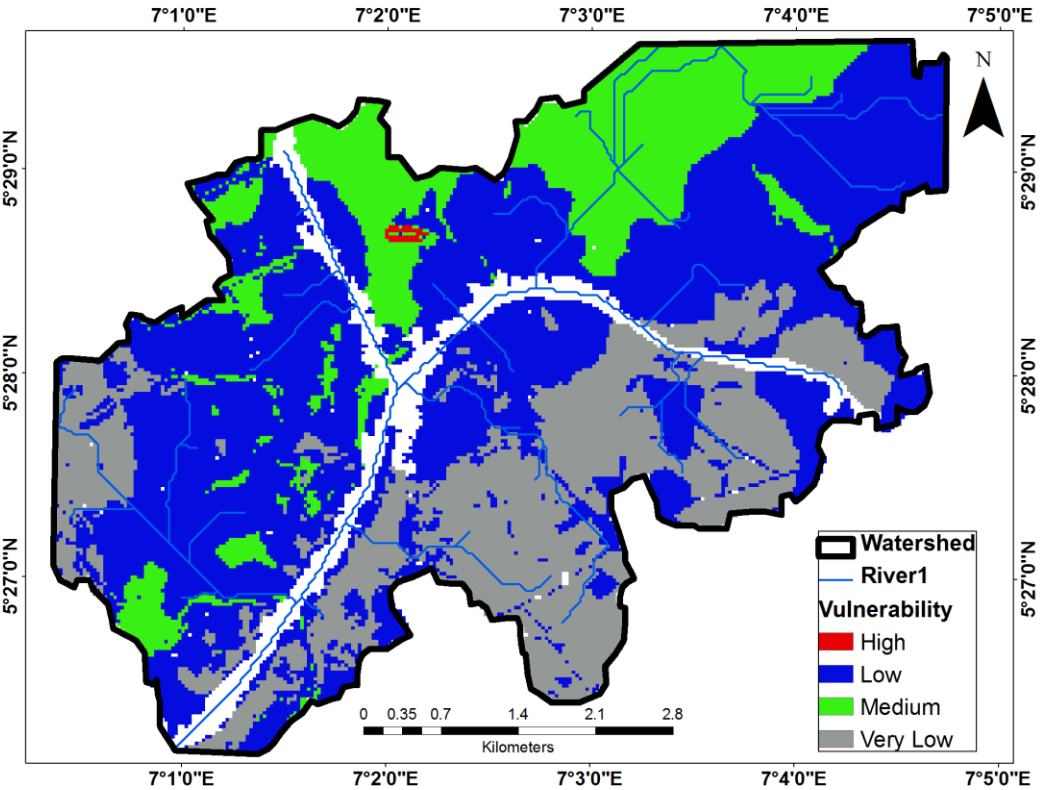

Figure 12: Scenario 3: Map showing Result of greater Weighting for Slope Layer

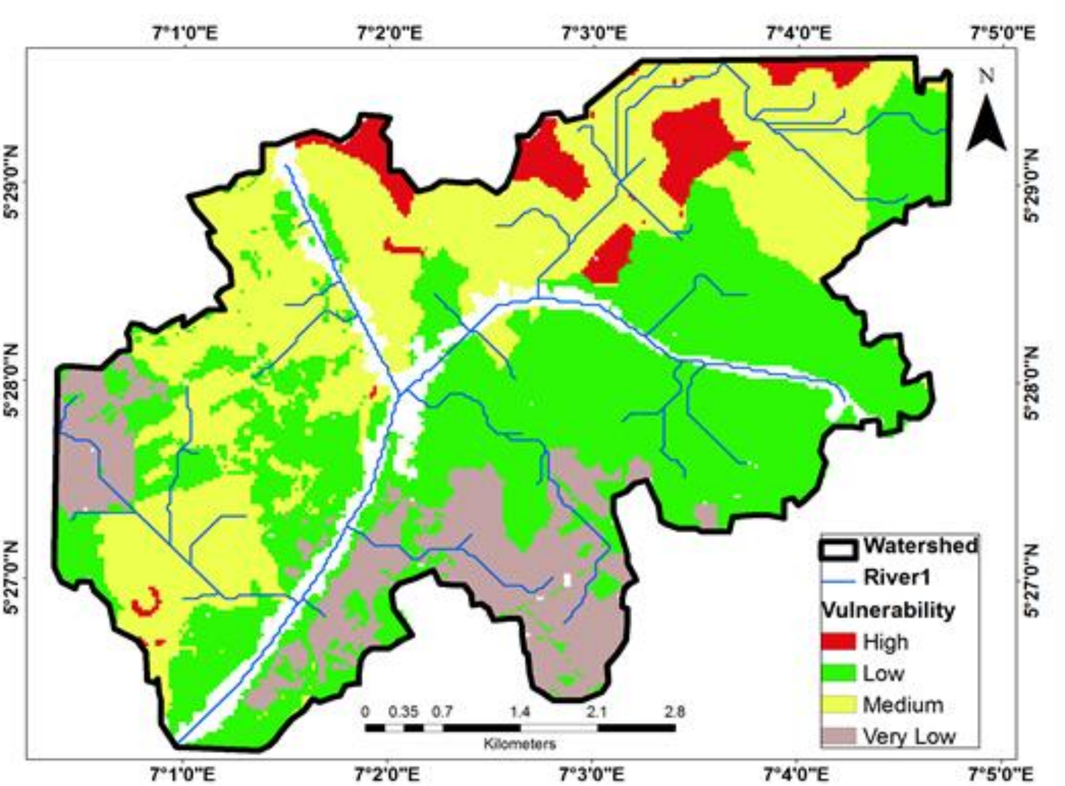

Figure 13: Scenario 4: Map showing Result of greater Weighting for Imperviousness Layer

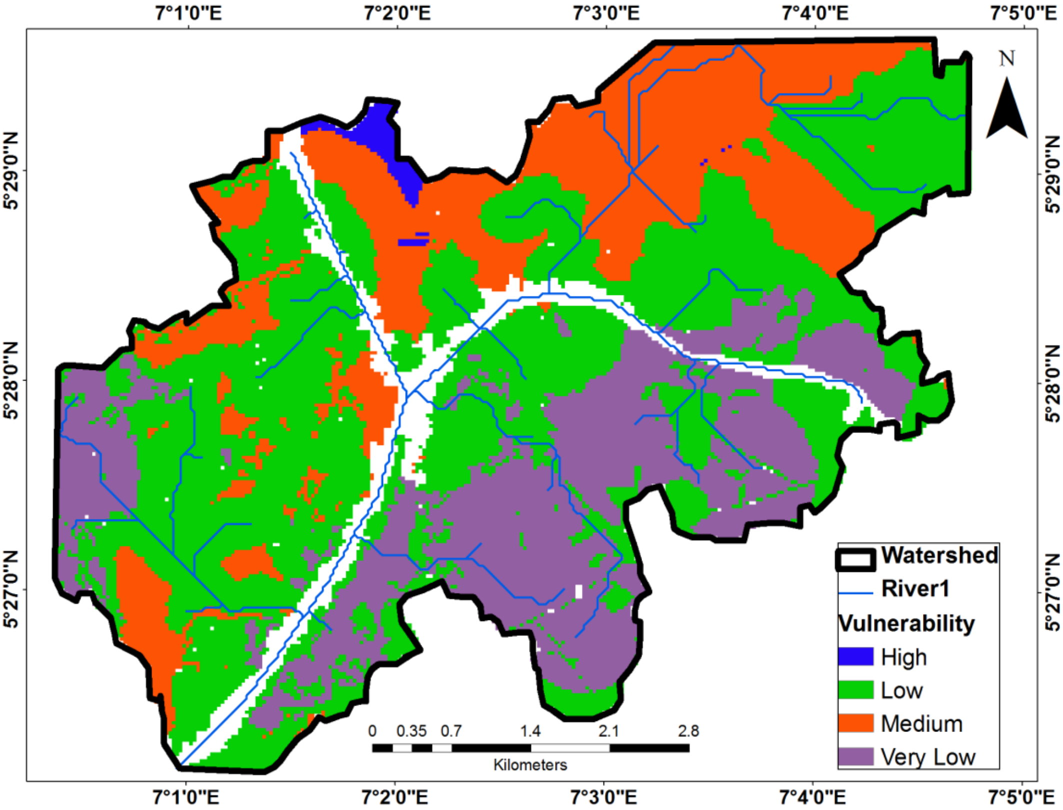

Figure 14: Scenario 6: Map showing Result of greater Weighting for Cost Distance Layer

Results of the different scenarios show a composite vulnerability that targets mainly medium and low vulnerability zones in the watershed. Scenario 2 (increased land use influence) had its highest areal extent in the medium vulnerability zones, while others had theirs in the low vulnerability zones.

Scenario 1 shows that equal influence of the environmental factors on the watershed will yield generally a low vulnerability potential of the watershed to contamination sources. While Scenario 2 displays the influence of land use activities which maintained a medium level of vulnerability potential but with the potential of increasing its vulnerability in the watershed. This may be inferred from the increasing rate of urbanisation in form infrastructural developments and sand excavation activities. Predominance of medium level of vulnerability in Scenario 4 is similar to that observed in Scenario 2. While the dominance of low vulnerability of the watershed can be said to be as a result of mainly the slope of the watershed which is relatively flat. logically this will reduce the rate of runoff in the study area as the reduction in run-off might lead to infiltration of water into the ground which is also dependent on the degree of imperviousness. This may also suggest a possibility of Non-point source pollutants migrating into ground water and probable percolation into surface water. The results also highlight the potential negative role land use practice in form of urbanisation (built-up, roads and indiscriminate waste dumpsites) will play on the watershed disturbance if not properly managed. Figure 15 below is a graph showing the areal extent per vulnerability classes for all the scenarios.

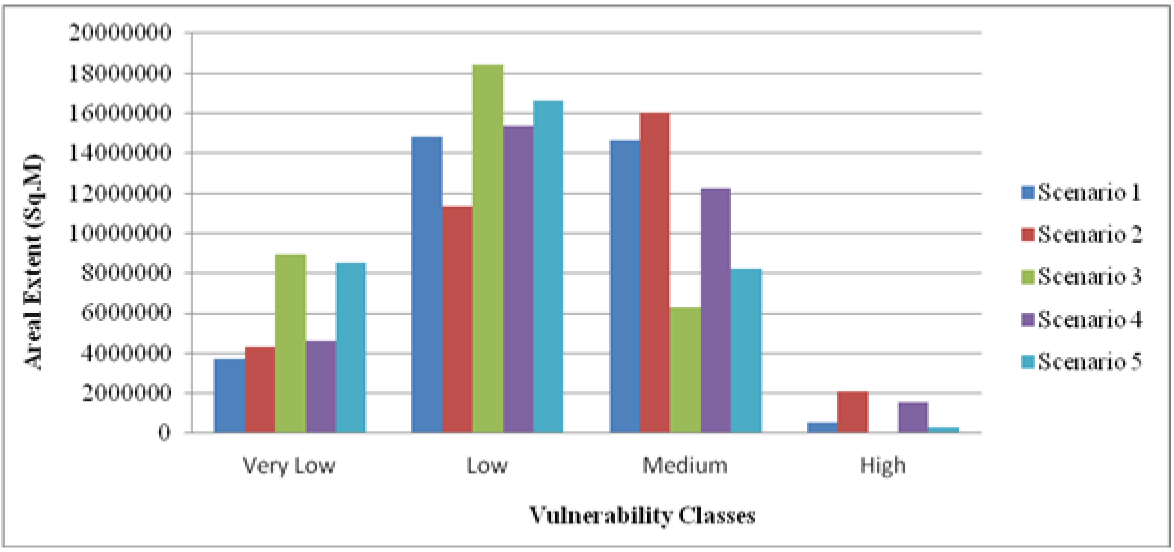

Figure 15: Areal Extent per Vulnerability Zone for all Scenario

CONCLUSION

The study has shown that the watershed has generally low and medium vulnerability potentials to contamination sources. Land use layer and impervious layer were observed from the spatial analysis to be the highest contributor to vulnerability potentials of the watershed. The implications are gradual degradation of the water resources and the consequent increase in the treatment cost. This may have contributed to the current lack of municipal pipe borne water supply in the area. Residents now rely on ground water supply for their water needs. GIS-based source water vulnerability assessment is imperative for water systems and localities in the determination of protection priorities for addressing contamination threats. The technology has the ability of integrating spatially referenced datasets required for the understanding of processes interacting in the watershed.

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